HAYATI Journal of Biosciences 22 (2015) 105–112

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HAYATI Journal of Biosciences

journal homepage: http://www.journals.elsevier.com/hayati-journal-of-biosciences

Original research article

The Distribution and Abundance of Black Band Disease and White Syndrome in Kepulauan Seribu, Indonesia

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ARTICLE INFO

Article history:
Received 3 July 2014
Accepted 2 December 2014
Available online 11 October 2015

KEYWORDS:
abundance,
black band,
disease,
Kepulauan Seribu,
Montipora spp.,
White syndrome

ABSTRACT

Coral diseases that have emerged since the early 1970s have caused significant regional ecological impacts. However, there has been a paucity of research into coral disease in South-East Asia, including Indonesia. This study provides baseline coral disease data in the Kepulauan Seribu Marine National Park. In this study we show a positive correlation between overall coral cover and the dominant reef building coral *Montipora* spp. and found two main diseases, black band disease (BBD) and WS, were highly prevalent throughout all reefs. Based on spatial location, the highest abundance of BBD (0.08 col./m^2) was found at sites nearer (zone 1) to the mainland, whilst for WS (0.05 col./m^2) highest abundance was found at middle sites (zone 2). According to the temporal data, the highest abundance of BBD (0.77 col./m^2) was found during the transition period (between wet and dry seasons), whereas for WS higher abundance occurred within the dry season (0.07 col./m^2). There was a significant difference in disease abundance among seasons which was correlated with increasing temperature and light intensity along with variations in total organic matters, nitrite and phosphate levels. Moreover, the middle sites experienced additional stress from the waste material originating from the mainland.

1. Introduction

Coral reefs are faced with unprecedented natural and anthropogenic disturbances. Even optimistic scenarios for environmental change anticipate mass declines in coral cover and species richness. The biggest threats to the longevity of coral reefs are often reported as being mass bleaching events and outbreaks of disease (Carpenter *et al.* 2008; Harvell *et al.* 2001; Hoegh-Guldberg, 1999). Disease can lead to significant decreases in live coral cover (Aeby *et al.* 2011), partial to whole-colony mortality and changes in community composition (Aronson and Precht, 1997; Beeden *et al.* 2008), which can jeopardize the entire reef ecosystem (Carpenter *et al.* 2008; Harvell *et al.* 1999; Hughes *et al.* 2003; Palmer *et al.* 2010, 2011; Raymundo *et al.* 2003). However, despite the biological and economic significance of coral reefs in the South-East Asian region, no systematic investigation of coral diseases in Indonesia has to date been conducted.

Disease outbreaks have been temporally and spatially linked to bleaching events and in some cases increases in disease prevalence have been associated with sea surface temperature (SST) anomalies (Bruno *et al.* 2007; Riegl, 2002; Selig *et al.* 2006). Currently, only eight coral diseases have been associated with specific microbial pathogens and most of these are regularly disputed (Goreau *et al.* 1998; Rosenberg and Ben-Haim, 2002).

The Kepulauan Seribu National Park, 45 km north of Jakarta, Indonesia, covers 159 km of reef tract. Despite its large area, much of the park is subjected to high levels of pollution as areas of the park are close to Jakarta's capital city with a population of 9.99 million (BPS, 2013). Waste water and sewage are the main sources of this pollution, originating from 13 rivers merging into Jakarta bay. Other pollution events such as oil spills are frequent and of major concern to reef health in this area. Despite these high levels of pollution, disease incidence has not currently been recorded to date.

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Peer review under responsibility of Institut Pertanian Bogor.

http://dx.doi.org/10.1016/j.hjb.2015.09.001

Black band disease (BBD) is a kind of coral disease caused by pathogenic microbial mat consortium which included five kinds of microorganisms. These are filamentous cyanobacterium *Phormidium corallyticum*, numerous heterotrophic bacteria (Garrett and Ducklow, 1975), marine fungi (Ramos-Flores, 1983) and both sulphide-oxidizing (Beggiatoa) and sulfate-reducing (Desulfovibrio) bacteria (Ducklow and Mitchell, 1979; Richardson, 1996). The cyanobacterial population which characterized with band color of blackish brown to red, the band 1 mm thick and ranges in width from 1 to 3 mm. BBD already found on *Montipora* spp. of encrusting, foliose and branching growth form. BBD was first found at the reefs off Belize, Puerto Rico, Florida and Bermuda and currently occurred at 36 countries including Indo-Pacific region.

Our study focused on assessing distribution and abundance of coral disease throughout the Kepulauan Seribu National Park as temporal data which spatially distributed from the nearest to the farthest of mainland. We hypothesize that the presence of coral disease will be correlated with proximity to the waste water, sewage source and other environmental factors attributed to the spread of the islands from the mainland to near pristine reefs. Our report is the first report on BBD in Kepulauan Seribu, Indonesia.

2. Materials and Methods

2.1. Study site

The study was conducted between June 2011 and May 2012 at two different depths, 1–3 m on reef flat for temporal data of six sites and 3–7 m on reef slope for spatial data of 12 sites. All research sites are under the authority of Kepulauan Seribu Marine National Park, except Pari Islands which is a research station of Research Center for Oceanography of the Indonesian Institute of Science. We surveyed eight sites within the Kepulauan Seribu Marine National Park, and four sites outside the Marine Park. The islands located in the Marine National Park included Pramuka, Karang Bongkok patchreefs, Kelapa, Kotok, Putri, Belanda, Penjaliran and Peteloran Islands, whereas those outside the Marine Park are south and east of Pari Islands, Tikus, Semak Daun and Pramuka Islands (Figure 1). Sites were chosen to cover the entire area of the Kepulauan Seribu system and varying levels of environmental factors which grouped according to the distance from the mainland. Furthermore, some of the islands in the study are inhabited (Pari, Pramuka and Kelapa Island.), whereas others are within the National Park.

2.2. Survey methods

2.2.1. Reefs condition data

Overall reef condition was assessed using the Line Intercept Transect method (English *et al.* 1997) on the reef flats by snorkeling and on the reef slopes by scuba diving. Three replicate transects were conducted at each site, 20 m in length. Life form and substrate were analyzed by using a common category according to English *et al.* (1997) and Gomez and Yap (1984) such as acropora branching, acropora tabulate, acropora digitate, coral branching, coral foliose, and other criteria such as macro algae, sponge and soft coral. There are 29 criteria based English *et al.* (1997).

2.2.2. Coral disease abundance

Corals infected by disease were recorded using a belt transect with a width of 1 m either side of the transect line. Transects line of 20 m in length with 3 replicates were conducted per site. Both spatial and temporal data at three different distances from the mainland were grouped as the nearest sites as zone 1 (South of Pari, East of Pari and North Tikus Is.), the middle sites as zone 2 (South of Pramuka Is., North of Parmuka Is., Karang Bongkok patchreefs, Kelapa Is., Semak Daun Is.) and the furthest away sites as zone 3 (Peteloran Is., Penjaliran Is., North of Jukung Is., North of Putri Is.). Spatial data were collected once, whereas there were 6 sites used for monitoring the temporal data and had permanent transects at South and East Pari Island (zone 1), South and North Pramuka Island (zone 2), and Peteloran and Penjaliran (zone 3). These data series covered 2 seasons (dry and rainy) with transition time between each season for over 1 year. Total coverage of transect data equals to 120 m^2. All infected colonies were recorded with the use of a Digital Canon Ixus 120 IS. Coral diseases were characterized using the descriptions by Raymundo *et al.* (2008) which explained that some diseases such as BBD, White syndrome (WS) and others compromise health such as coral space competition with other species of coral, algae, sponge and sedimentation. Identification also used the Australian Institute of Marine Science (AIMS) coral disease identification cards and photographs compiled by Willis *et al.* (2004).

2.2.3. Water quality data

Environmental parameters were recorded temporally at six of the sites for dissolve oxygen, salinity, nitrate, phosphate, total organic matters (TOMs), however light intensity and temperature (recorded by Hobo data loggers) were only recorded at one location per group (middle, near and far). The data included both physical parameters such as depth, water temperature (by Hobo data logger), visibility (by Secchi disk), current (by current drought), light intensity (by Hobo data logger), and chemical parameters such as dissolved oxygen, nitrate, and ortho-phosphate. The measurements of these parameters were taken at the surface for dissolved oxygen, salinity and temperature by using a YSI 556 Multi-Probe System, whereas TOM, ortho-phosphate, and nitrite were sampled and analyzed by the Environmental Testing Productivity and Water Laboratory at the Department of Water Resources Management, Bogor Agricultural University.

2.3. Statistical analyses

Abundance of diseased corals was calculated by dividing the number of disease colonies by the total area of the belt transect (120 m^2). The Kruskal–Wallis test was used to compare the abundance of coral disease between sites and season. The relationship between live coral cover and *Montipora* spp. coral cover within and between sites was conducted using a regression test. Water quality parameters were analyzed by using Multivariate Analysis of Variance (MANOVA) analysis to depict differences between the study sites.

3. Results

A total area of 2160 m^2 from 18 sites was surveyed to get data for coral distribution and abundance, and six permanent sites were used for temporal analysis of coral disease abundance during the study.

3.1. Reefs condition on research sites

Live coral cover ranged from 19% to 81% across the sites, with an average of 49.38%, classifying the park reefs to be in good condition according to coral status based on life coral percentage (Gomez and Yap, 1984). *Montipora* spp. was found to dominate the reef, accounting for an average of 94.8% of this live coral cover. There was a strong relationship between total live coral cover and the dominant reef builder *Montipora* spp. cover ($R^2 = 0.91$) at each site (Figure 2). Due to this high abundance of *Montipora* spp. these corals proved to be the ideal candidate for identifying and monitoring diseases in corals at the sites, as well as their dominance demonstrating how critical they are to reef condition/health.

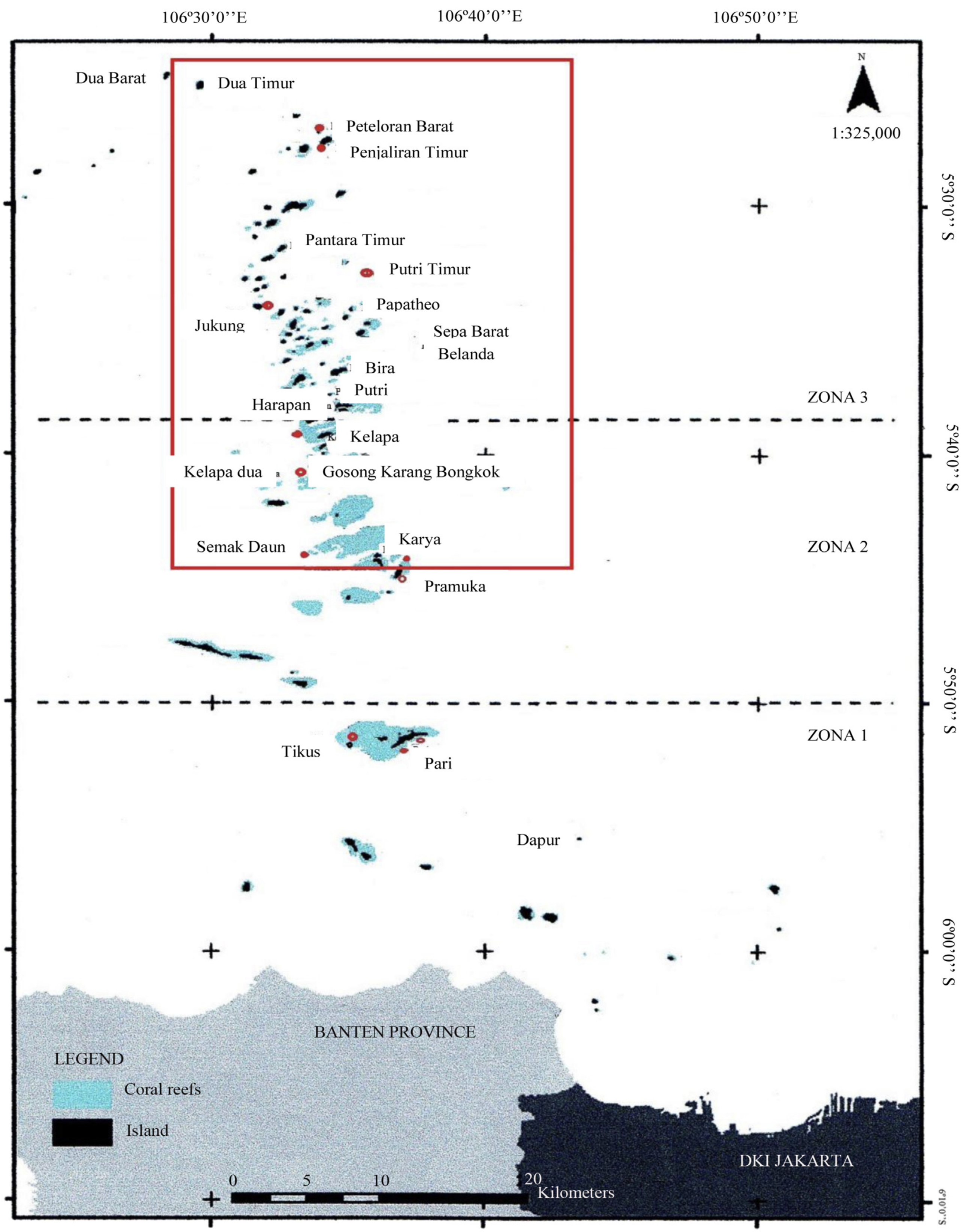

Figure 1. Research sites. Located the nearest (zone 1), middle (zone 2), and the farthest from the mainland (zone 3; Farhan and Lim, 2012). Red square is Marine National Park area.

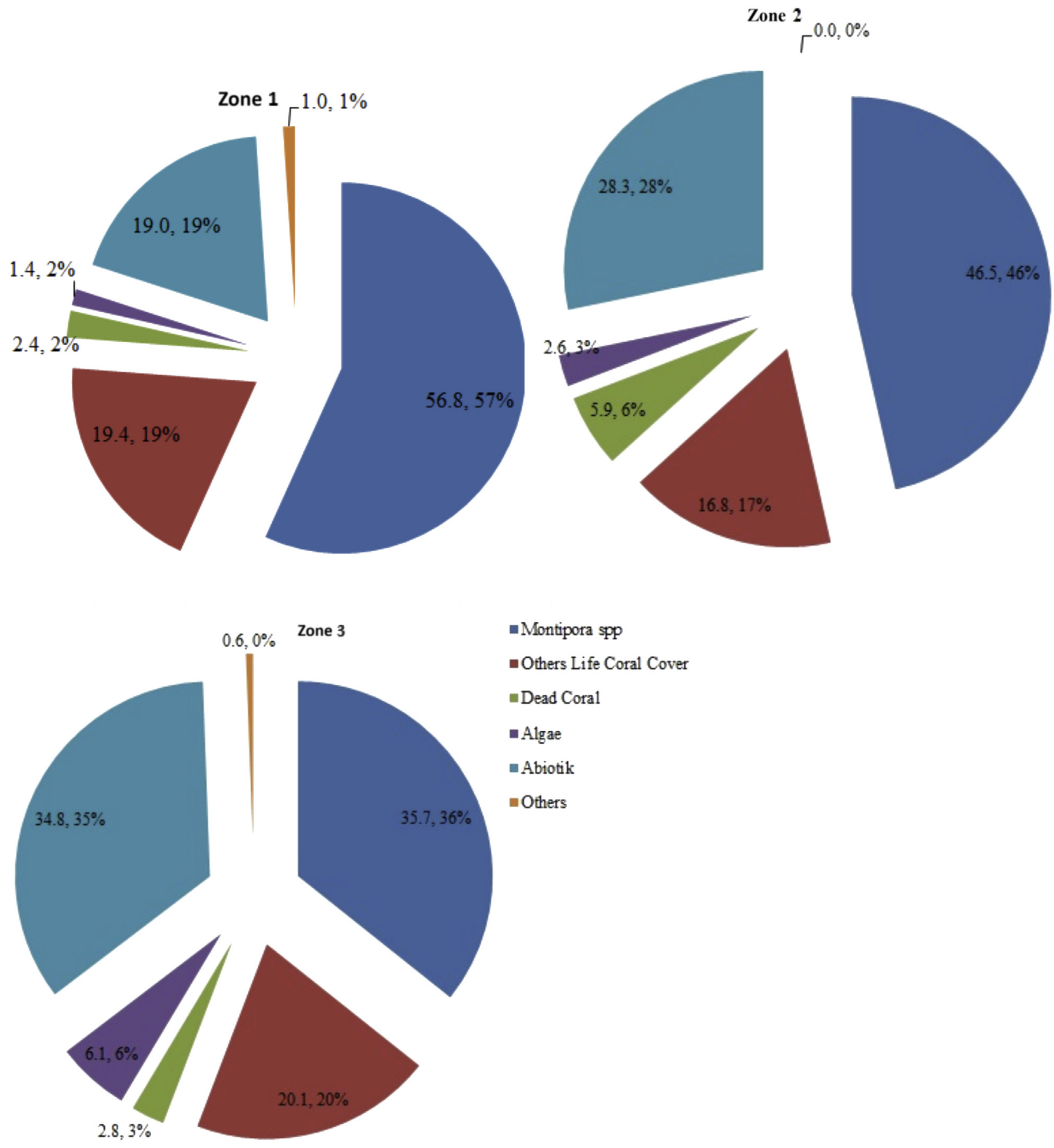

Figure 2. Percentage of live coral cover. *Montipora* spp. and other biota coverage according to line intercept transect data (English *et al.* 1997) over the different sites surveyed split between the three grouped sites (the nearest, the middle and the farthest) with two replication of each group at Kepulauan Seribu, Jakarta.

3.2. Spatial coral disease abundance

A total of 121 colonies showed signs of diseases and 57 colonies showed compromised health status over the 12 sites surveyed. The diseases recorded included BBD and WS.

3.2.1. Black band disease

The presence of BBD in the Kepulauan Seribu was found to be associated with only one genus, *Montipora* spp. There were 9 locations where BBD was recorded (Figure 3). BBD abundance ranged from 0.092 col./m^2 (East of Pari and Penjaliran Is.) to 0.15 col./m^2 (North of Pramuka Is.). Overall on average, corals were found to suffer more from BBD (0.08 col./m^2) at zone 1 than WS (0.05 col./m^2). However, there was no significant difference ($\chi^2 = 1.043$, asymptotic significance = 0.307) between corals with BBD and WS. According to the group of sites, the highest abundance of disease was found within zone 1 to the mainland (0.08 ± 33.25 col/m^2), followed by zone 2 (0.05 ± 18.62 col./m^2) and the lowest was found at zone 3 (0.03 ± 24.50 col./m^2). Higher BBD abundance during June–July 2011, at the sites closer to the mainland, was related with the dry season where mostly material waste is observed to move

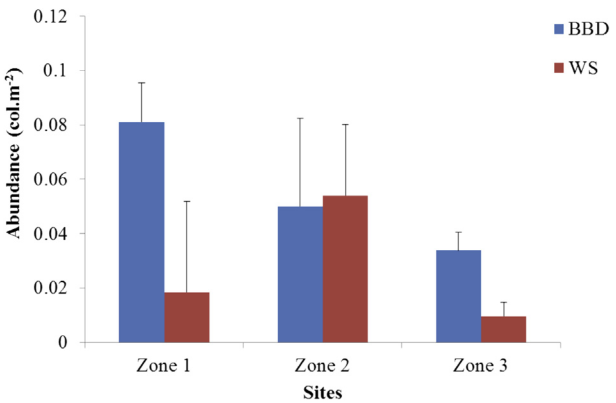

Figure 3. The average abundance of BBD and WS (col./m^2) on three zones with four sites each zone in dry season at Kepulauan Seribu. Data presented as the means ± standard deviation for each sites on three zones. BBS = black band disease; WS = White syndrome.

from the mainland to the outside reefs where one of our sites, the Kepulauan Seribu are located. Interestingly, there was no significant difference between BBD abundance among the three groups sites (analysis of variance, F = 0.992, $p = 0.408$).

According to the time series data on the six permanent sites, BBD abundance was found to be highest in zone 3 (0.53 ± 0.52 col./m^2) and lowest at zone 1 (0.23 ± 0.17 col./m^2). These results suggest that there are other factors causing the BBD abundance beside anthropogenic pollution seen during the wet season. According to the Kruskal–Wallis test, there was a significant difference of BBD abundance between zone 1 sites and zone 3 sites on this study ($\chi^2 = 8.67$, Asymp Sig. = 0.003) (Table 1).

3.2.2. White syndrome

WS was another common disease found associated with the coral *Montipora* spp. and *Acropora* spp. Over the 12 sites, the highest abundance of corals showing signs of WS were located at South of Pramuka Is. (0.11 col./m^2), Kelapa Is. (0.07 col./m^2) and Karang Bongkok (0.05 col./m^2). WS was more abundant in zone 2 (0.10 col./m^2) and least abundant at zone 3 (0.05 col./m^2). However, there was no significant difference between groups sites (F = 2.962, sig = 0.103, Table 1).

3.3. Temporal coral disease abundance

Total reef area of 720 m^2 was assessed for coral disease abundance spanning two seasons including dry and wet and the transition time between the two. These were conducted on permanent transects at six sites (two sites from each of the representative location; zone 1, 2 and 3 sites in Kepulauan Seribu). The same diseases as recorded during the spatial sampling were seen at these sites with total abundance of disease colony being higher for those with BBD (9.08 col./m^2) than WS (1.58 col./m^2). There was a significant difference between both disease types at the different sites ($\chi^2 = 30.009$, Asymp. Sig. = 0.001) and between seasons ($\chi^2 = 10.988$, Asymp. Sig. = 0.001).

Table 1. Statistical test by the Kruskal–Wallis test of variance of BBD, WS on 12 sites spatially, the nearest (N), the middle (M) and the farthest (F) sites from the mainland. There was significant among site (*)

Spatial comparison	df	BBD		WS	
		χ^2	Asymp. sig.	χ^2	Asymp. sig.
N × M × F (all)	2	2.175	0.337	12.89	0.002*
N × M	1	0.886	0.346	10.79	0.001*
N × F	1	8.665	0.003*	6.11	0.013*
M × F	1	0.344	0.558	2.32	0.128

BBS = black band disease; df = degrees of freedom; WS = White syndrome.

Table 2. Statistical test by the Kruskal–Wallis test of variance of BBD and WS abundant on different seasons, dry (D), transition (T) and rainy (R) season. There was significant among season (*)

Seasonal comparison	df	BBD		WS	
		χ^2	Asymp. sig.	χ^2	Asymp. sig.
D × T × R (all)	2	9.807	0.007*	3.960	0.138
D × T	1	7.912	0.005*	0.018	0.895
D × R	1	4.271	0.039	3.412	0.065
T × R	1	1.310	0.252	2.576	0.109

BBS = black band disease; df = degrees of freedom; WS = White syndrome.

3.3.1. Black band disease

The highest abundance of BBD was found during the transition period and the lowest during the dry season (transition 0.77 ± 0.73 col./m^2, $N = 6$; rainy 0.35 ± 0.20 col./m^2, $N = 8$; and dry 0.16 ± 0.14 col./m^2, $N = 9$). There was a significant difference of BBD abundance between seasons ($\chi^2 = 9.807$, Asymp. Sig. = 0.07) (Table 2).

Season was shown to influence the abundance of BBD in Kepulauan Seribu. This is likely due to the temperature and light intensity levels. A higher abundance of BBD was recorded during the transition season: Pramuka Island (1.02 col./m^2), Pari Island (0.41 col./m^2) and Penjaliran Island (0.29 col./m^2). During this period, temperature was 0.35 °C higher than the rainy and dry seasons, whereas light levels were also higher (7970.15 lux) in comparison to rainy (5233.07 lux) and dry (1631.14 lux) seasons.

3.3.2. White syndrome

WS was found in all seasons with the highest during the dry season (0.074 ± 0.11 col./m^2, $N = 9$) and the lowest within the rainy season (0.03 ± 0.02 col./m^2, $N = 8$) (Figure 4). However, there was no significant difference on WS abundance between seasons ($\chi^2 = 3.96$, Asymp. Sig. = 0.138) (Table 2).

3.4. Water quality

SST varied very little between sites (Table 3). Salinity ranged from 32.19 to 33.92‰. Light intensity in zone 2 (4944.79 ± 3709.13 lux) was higher than zone 1 (4325.29 ± 6468.14 lux) and zone 3 (3045.35 ± 3031.60 lux). NO_3-N was higher in zones 2 and 3 compared with that in zone 1 which ranged from 0.005 mg/L to 0.016 mg/L. Only the current flow was significantly different between sites being much greater in zone 3 (0.087 ± 0.030 m/s) compared to those in zone 2 (0.076 ± 0.023 m/s) and zone 1 (0.075 ± 0.031 m/s) (Table 3).

4. Discussion

4.1. Reef condition on research site

This study is the first comprehensive analysis of diseases affecting corals in Indonesia and highlights that reefs dominated by corals from the genus *Montipora* spp. are susceptible to a variety of different diseases such as BBD and WS. The two most dominant coral diseases frequently detected were BBD and WS, affected both *Montipora* spp. and *Acropora* spp. Interestingly, the diseases were only recorded in shallow water, less than 1.5 m depths. However, WS was also found in deeper water, more than 1.5 m, at outside the transect.

4.2. Spatial and temporal abundance of coral disease

BBD was found to be present throughout all seasons and at all sites which reached the peak on transition time until the early rainy

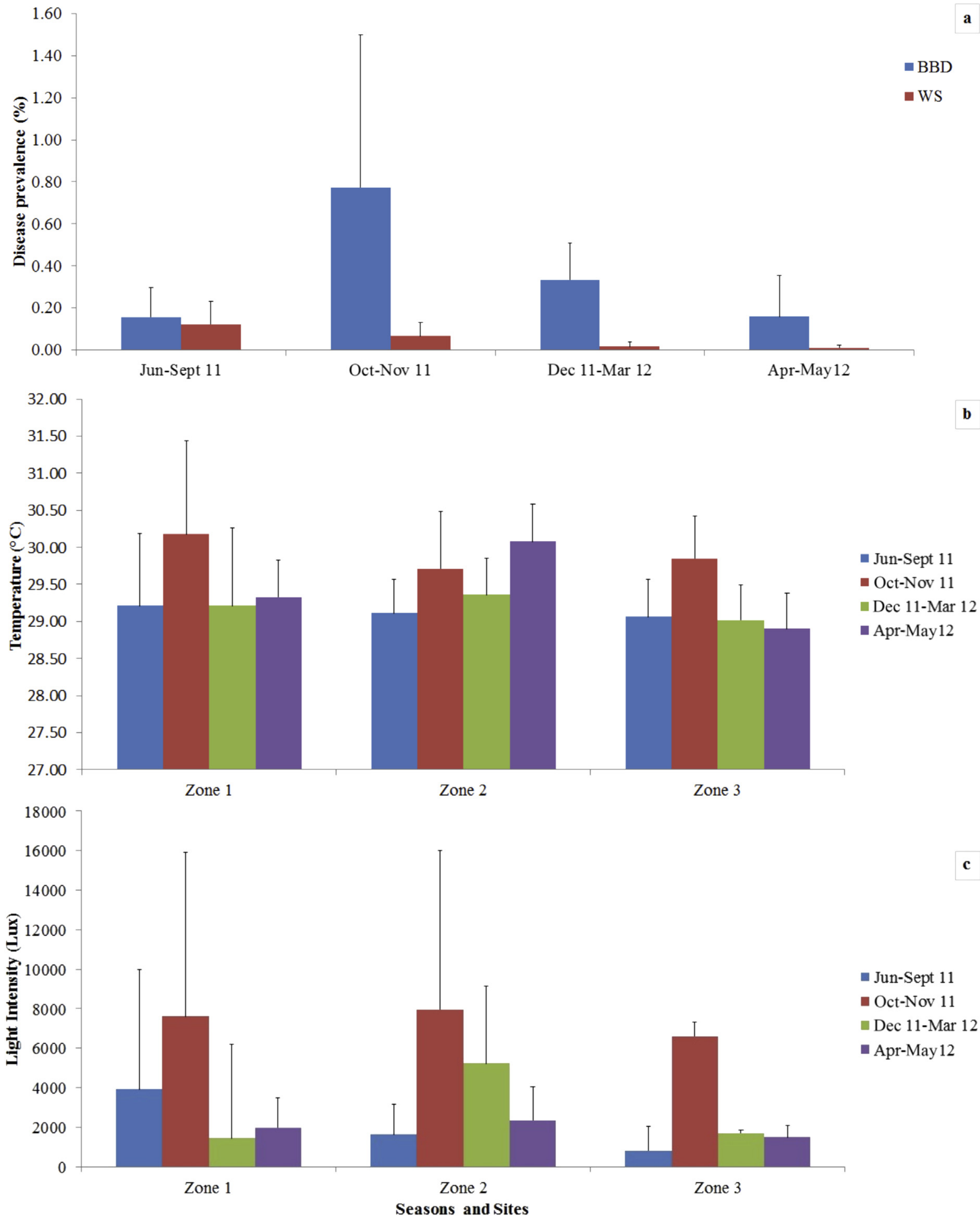

Figure 4. Coral disease prevalence, temperature, and light intensity during study. (A) the abundance of black band disease and white syndrome on the locations in dry, transition, rainy and transition season, (B) average of temperature ($n = 5481$), (C) the average of light intensity ($n = 5481$) on different seasons recorded by Hobo data logger on three permanent sites; nearest (zone 1), middle (zone 2), and farthest (zone 3) as spatially from the mainland (Java Island) in Kepulauan Seribu. Data presented as the means ± standard deviation for each site on three zones.

season in November and December 2011. The abundance of coral disease was closely related with the temperature and light intensity, when both parameters increased, disease abundance subsequently increased as well, supporting the effect of temperature and light intensity on outbreaks of coral disease (Boyett *et al.* 2007; Haapkylä *et al.* 2010). The abundance of corals showing signs of BBD was higher in the locations closer to the mainland. This is likely due to the impact of material waste which was significantly higher at these sites than those further away. This result can be partially explained by the direction of the currents at the study sites. Waste

Table 3. The average and standard deviation of measurement result of *in situ* waters quality parameter. There was significant among zone (*)

Parameter	Unit	Sites		
		Zone 1	Zone 2	Zone 3
Temperature	°C	29.28 ± 0.71	29.42 ± 0.46	29.27 ± 0.50
Salinity	‰	32.19 ± 3.61	33.92 ± 2.30	32.52 ± 1.89
DO	mg/L	8.62 ± 2.30	7.28 ± 0.75	7.09 ± 0.84
Turbidity	NTU	0.37 ± 0.31	0.38 ± 0.21	0.41 ± 0.20
TDS	mg/L	32.74 ± 3.14	28.62 ± 12.11	25.61 ± 12.67
Current	m/s	0.087 ± 0.030	0.076 ± 0.023	0.075 ± 0.031
Light intensity	lux	3693 ± 2876.50	3641.10 ± 3014.00	4435.19 ± 4491.44
TOM	$mgKMnO_4/L$	24.36 ± 16.02*	23.92 ± 14.45*	28.53 ± 22.53*
PO_4-P	mg/L	0.009 ± 0.005	0.006 ± 0.005	0.007 ± 0.005
NO_3-N	mg/L	0.003 ± 0.002	0.005 ± 0.006	0.005 ± 0.006

DO = dissolved oxygen; NTU = Nephelometric turbidity units; TDS = Total dissolved solids; TOM = total organic matter.

from the Jakarta Bay can flow through the entire Kepulauan Seribu from the nearest islands than those further away during the dry season, whereas during the transition period the current velocity is slower and waste material can be observed on the surface of the water. During the rainy season, the waste material is moved in the opposite direction from the furthest away areas to the nearest sites. So, in theory, those sites in the middle are exposed twice as much to waste material that can cause damage to the corals than those in other zones. Although the results appear to support this theory, further works highlighting that the waste sewage harbors specific coral pathogens should be conducted.

Only *Montipora* spp. were found to be infected by BBD in Seribu Island. The disease appeared not to be transferred to other species even though they were often adjacent to diseased *Montiporas*. This result is in contrast to that reported by Frias-Lopez *et al.* (2003), in which they found that the BBD-infected coral can easily infect neighboring corals no matter what the species are.

WS infected both *Montipora* spp. and *Acropora* spp. spatially across the research sites throughout the year, but mostly higher on the dry season due to the temperature and light intensity stress on this season.

4.3. Effect of environmental factors on disease abundance

This study highlights that the corals which experience higher light intensity in the shallow warmer water are more likely to contract the two most dominant diseases recorded in this study (BBD and WS). BBD is thought to be caused by a consortium of bacterial pathogens dominated by species of Cyanobacteria (Rützler *et al.* 1983). This study found that BBD was limited to corals above 1.5 m. We assume that this is because cyanobacterium depends on sunlight for photosynthesis (Richardson *et al.* 1997). Here, we show no presence of BBD on the deeper transects, again supporting previous studies which showed that BBD is found no deeper than 6.6 m (Richardson *et al.* 1997; Rützler *et al.* 1983).

Certain species of corals have been shown to be more susceptible to catching diseases, largely due to their varying levels of immunity (Palmer *et al.* 2011). *Montipora aequituberculata* and *Montipora crassituberculata* in particular have been classified as sensitive species due to the variation of environmental parameter such as turbidity, current flow and temperature (Phongsuwan and Chansang, 2012). The relationship between the abundance of BBD and increases in SST has been well documented in previous studies and is seen in this study as well (Bruckner and Bruckner, 1997; Edmunds, 1999; Kuta and Richardson, 1996; Rodriguez and Croquer, 2008; Sato *et al.* 2009; Voss and Richardson, 2006; Zvuloni *et al.* 2009).

The peak abundance of WS happened in dry season, earlier than the peak of BBD abundance. Temperature and light intensity started increasing sharply in dry season that caused both corals *Montipora* spp. and *Acropora* spp. stressed and prone to WS, whereas the peak abundance of BBD happened in the same time when temperature and light intensity reached the peak value on transition time.

The diseases detected in this study showed certain relationships with the environmental parameters monitored during the study. In particular, temperature, depth and concentration of ortho-phosphate and nitrite had strong correlations with the presence of BBD. Discharge of nutrients from sewage sources, increased sedimentation, and water influx from the mainland are potential factors that support the emergence of these diseases in this particular area (Bruckner and Bruckner, 1997; Kuta and Richardson, 2002). Although Cleary *et al.* (2006) described the anthropogenic factors which significantly stress the corals, in the Kepulauan Seribu there were a gradient of decreasing effects the further away the area from the Bay of Jakarta. This study shows that those within the middle areas were more likely to show signs of stress/disease.

In conclusion, this is the first record of a significant amount of different coral diseases occurring within the Kepulauan Seribu reef system, Indonesia. The diseases were more commonly confined to the shallower areas of reef tract and dominated the major reef building coral of *Montipora* spp. Coral diseases are likely to have a serious deleterious impact on the dominant reef building coral in this area. The highest abundance of disease occurred within the transition time between the dry and rainy seasons (October–November 2011), which in turn can be linked directly to both increasing temperature and high levels of light intensity. Other increasing factors such as TOM also correlated with higher than average level of coral disease. Abundance of diseases such as BBD over the 12 survey sites showed that abundance was higher in the islands within the middle of the surveyed sites. This is likely due to these sites being exposed twice as much sewage during the year when compared to sites near the mainland and those furthest away.

Conflict of interest

None.

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